# DEVELOPMENT OF AN ECONOMIC WARRANT FOR THE CONSTRUCTION OF RIGHT-TURN DECELERATION LANES

MAY 1970 - NUMBER 12

BY

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JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Final Report

# DEVELOPMENT OF AN ECONOMIC WARRANT FOR THE CONSTRUCTION OF RIGHT-TURN DECELERATION LANES

TO: J. F. McLaughlin, Director
Joint Highway Research Project

May 27, 1975

File: 3-8-34

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-17HH

The attached Final Report titled "Development of an Economic Warrant for the Construction of Right-Turn Deceleration Lanes" has been authored by Mr. Michael Alexander, Graduate Assistant in Research on our staff. Professor H. L. Michael served as the director of the study.

The report includes a model for predicting the delay at intersections or major access points where a right turn lane might be warranted and outlines a technique for evaluating the econimic benefits from construction of such a lane and comparing these with the costs. Typical conditions where such a lane is warranted are shown as examples in this report.

The report is presented for acceptance as fulfilling the objectives of this approved study.

Respectfully submitted,

Harold L Michael

Harold L. Michael
Associate Director

HLM/lm

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Final Report

# DEVELOPMENT OF AN ECONOMIC WARRANT FOR THE CONSTRUCTION OF RIGHT-TURN DECELERATION LANES

by

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Joint Highway Research Project

File: 3-8-34
Project: C-36-17HH

Purdue University
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May 27, 1970

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# ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Professor Harold L. Michael, Associate Director of the Joint Highway Research Project, for his guidance during the study and for his expert review of the manuscript; to Professor William L. Grecco of the Joint Highway Research Project, and to Professor James R. Buck of the School of Industrial Engineering for their reviews of the manuscript.

The author also wishes to express his appreciation to Mr. George Stafford, who helped greatly in the data collection; and to Mr. Richard James for his advice on the statistical analysis of the data.

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# ABSTRACT

Alexander, Michael Howard. MSCE, Purdue University, June 1970. Development of an Economic Warrant for the Construction of Right-Turn Deceleration Lanes. Major Professor: Harold L. Michael.

The objective of this research was to develop an economic warrant for the construction of right-turn deceleration lanes. To achieve this objective, delays and accidents to through vehicles caused by right-turning vehicles were studied at three field sites with right-turn deceleration lanes and at seven field sites without such deceleration lanes. Delays were studied for the daylight-weekday hours, Monday through Friday, 6 A.M. to 6 P.M.

It was found that delays to through vehicles caused by right-turning vehicles were virtually eliminated at the sites with right-turn deceleration lanes. Accidents considered preventable with a right-turn deceleration lane did not occur at the three sites with such deceleration lanes; however, a few such accidents did occur at almost every site without right-turn deceleration lanes.

A regression equation was developed that can be used to predict the seconds of delay per hour to the approach through traffic caused by right-turning vehicles. A similar equation to predict accidents reliably could not be developed because of data limitations.

This research proposes that an economic warrant be used for determining when a right-turn deceleration lane should be constructed. Such construction becomes feasible when the annual economic benefits

resulting from decreased daytime delays are equal to or exceed the annual costs of constructing, operating and maintaining such a lane. In marginal situations, other benefits such as reduced night time delays and fewer accidents should also be considered.

# INTRODUCTION

One problem that exists today on many rural highways and on many urban streets at the intersection approaches and at entrances to traffic generators is that there is no storage space and/or deceleration space provided for turning movements. The effect of this design omission is to require turning vehicles to decelerate in the traffic stream to a slow speed so that the turn can be made. The results are delays and accidents to some of the vehicles in the traffic stream. Delays result from the slowing down of non-turning vehicles as they pass through the intersection area. Accidents are caused by the increased speed differentials between through vehicles and turning vehicles. Benefits to the highway system from an increased use of deceleration lanes may be lower costs to the traveling public. These costs may be lower because there will most likely be less delay and fewer accidents where deceleration lanes are used.

This particular research project was concerned with deceleration lanes for right turns at intersections and other access points. At the selected study locations there was stop control for the traffic crossing or entering the highway being studied and no control for the through traffic. If there were stop control for the through traffic, it would always be delayed at the intersection or access point and deceleration lanes would not be applicable.

The purpose of this research project was to develop warrants for deceleration lanes for right turns at intersections and other access points. It was hoped that warrants could be developed which would use traffic volumes as the measure of the need for deceleration lanes because volumes are easily obtained.

Designers frequently have employed deceleration lanes on high volume highways where the number of right turns was estimated to be large. Such use was justified by the minimization of conflicts between numerous right-turning and through vehicles. The designer, however, had few guidelines for including such deceleration lanes on moderate and low volume roads. This research project, therefore, was restricted to highways carrying between 2500 and 16,000 vehicles per day, with emphasis on the 2500 to 7000 volume highways.

## REVIEW OF LITERATURE

A Policy on Geometric Design of Rural Highways (1)* states that, "deceleration lanes always are advantageous, particularly on high speed roads, because the driver of a vehicle leaving the highway has no choice but to slow down on the through traffic lane if a deceleration lane is not provided. The failure of following drivers to brake due to inalertness is the cause of many rear-end collisions."

Some observations about speed-change lanes have led to the following conclusions by the AASHO Policy Manual (1) noted above:

> "(a) Speed-change lanes are warranted on high speed and on high volume highways where a change in speed is necessary for vehicles entering or leaving the through traffic lanes.
>
> "(b) All drivers do not use speed-change lanes in the same manner, some utilizing little of the facility available, but as a whole these lanes are used sufficiently to improve the overall safety and operation of the highway.
>
> "(c) Utilization of speed-change lanes varies with volume, with the majority of drivers using them at high volumes.
>
> . . . . . . . . . . . . . . . . . . . . . . . . . .
>
> "(e) Deceleration lanes on the approaches to intersections at grade, which also function as storage lanes for turning traffic, are particularly advantageous, and experience with them generally has been favorable. Such lanes reduce hazard and increase capacity. . . . "

---

*The numbers in the parenthesis refer to numbers in the bibliography.

The Manual of Geometric Design Standards for Canadian Roads and Streets (3) states recommendations for constructing a speed-change lane which include:

> "(a) at an intersection when the numbers of decelerating or accelerating vehicles compared to the through traffic volume would create undue hazards, . . ."

However, in the AASHO Policy Manual (1) it is stated that:

> "Warrants for the use of speed-change lanes cannot be stated definitely. There are many factors to be considered, namely: speeds, traffic volumes, capacity, type of highway and service provided, arrangement and frequency of intersections, accident experience, etc. . . ."

Furthermore, in the Canadian Design Manual (3) it is stated that, "it is impossible to give precise warrants for the use of intersection auxiliary lanes."

During a review of the literature no studies were found that attempted to establish such warrants for deceleration lanes. The purpose of this research project was to establish warrants for the construction of right-turn deceleration lanes.

# PLAN OF STUDY

One type of warrant possible of determination is an economic warrant, the conditions under which benefits received from construction of a right-turn deceleration lane exceed the costs of constructing and maintaining such a lane. An evaluation of such benefits at several field sites in the vicinity of Lafayette, Indiana, and comparison of such benefits with the costs of a deceleration lane were initial goals of this research.

The major benefits that accrue from the use of a deceleration lane are less delay and fewer accidents to the through traffic on the highway. If an economic value could be placed on the above two quantities, these values would be economic benefits accruing from the use of a right-turn deceleration lane.

As current design procedures recommend the use of a deceleration lane on high volume roads (1), it was decided to restrict this study to low to moderate volumes on two lane, two-way highways. Such roads are most common for such volumes and the absence of a deceleration lane on two lane, two-way roads is more restrictive to through vehicles than such absence on multilane roadways. On two lane, two-way roads through vehicles have less opportunity to pass the turning vehicle because of opposing traffic in the passing lane and consequently suffer greater delays.

To select field sites, the investigator drove all two lane, two-way roads in the vicinity of Lafayette, Indiana. Extension of the study to more distant locations was not attempted because of time restrictions of the investigator and the belief that geographic location of the sites would not be a major factor in evaluating time and safety benefits.

Sites were desired which had a range of right turns from few to many. Access points to commercial activities, schools, and other traffic generators as well as highway intersections were given consideration.

Ten sites were finally selected, of which three had deceleration lanes. The reason ten locations were used is that this number provided reasonable coverage of the volume range desired and included locations with and without deceleration lanes. Ten was also the practical number of locations that could be studied in the time period of this research project.

Sites with deceleration lanes were studied so that the effects of a deceleration lane on delay times and accidents could be substantiated. The AASHO Policy Manual (1) infers that delay times and accidents will be substantially reduced or virtually eliminated where a deceleration lane is used. It was felt desirable, however, to verify this belief and determine the amount of benefits by field observation of three sites.

The weekday-daylight hours, Monday through Friday, 6 A.M. to 6 P.M., were chosen as the time periods in which delay data would be collected. These time periods were chosen because they contained the majority of the traffic during the day and contained most of the work traffic, those trips which would benefit most from a reduction in delays. The daylight

hours were also more amenable to collection of delay data.

The 20-pen recorder used to record the delay times could operate for an uninterrupted period of three hours. Therefore, the maximum time period used for study at a site was three hours. A sample of data collected at a site consisted of delay and volume data for a one-hour period.

Three locations were studied for two one-hour periods and the remaining seven sites were studied for at least three one-hour periods. Data were collected at some of the seven sites for nine one-hour periods (three consecutive one-hour periods at a time) on different weekdays in different weeks. Delay data were collected on all five weekdays and for different time periods during each day so that the data obtained would be representative of delay during the daylight-weekday hours, 6 A.M. to 6 P.M.

The accident data at each site were studied by reviewing the accident records filed by the police investigators.

# PROCEDURE

## Study Locations

The nine intersections and one major access point that were studied are located in Tippecanoe County, Indiana (Figure 1). The ten locations are detailed in Figure 2 and the geometrics of each location are given in Appendix A. The approximate 1970 population of the county was 100,000.

Study locations were chosen where traffic crossing or entering the through highway at an intersection or access point was required to stop. This type of control was selected because if there were stop control for the through traffic it would always be delayed, a condition not appropriate for study in this research.

The study locations had the following characteristics:

1. No traffic control for the through traffic
2. Stop control for traffic crossing or entering the through highway
3. Access to through highway was at an approximate right-angle
4. Rural or urban location

Of the ten locations, two intersections and the one access point had deceleration lanes. Access points without deceleration lanes were not studied because no major access points on two lane, two-way roads could be located. Summary characteristics of the study locations are given in Table.1.

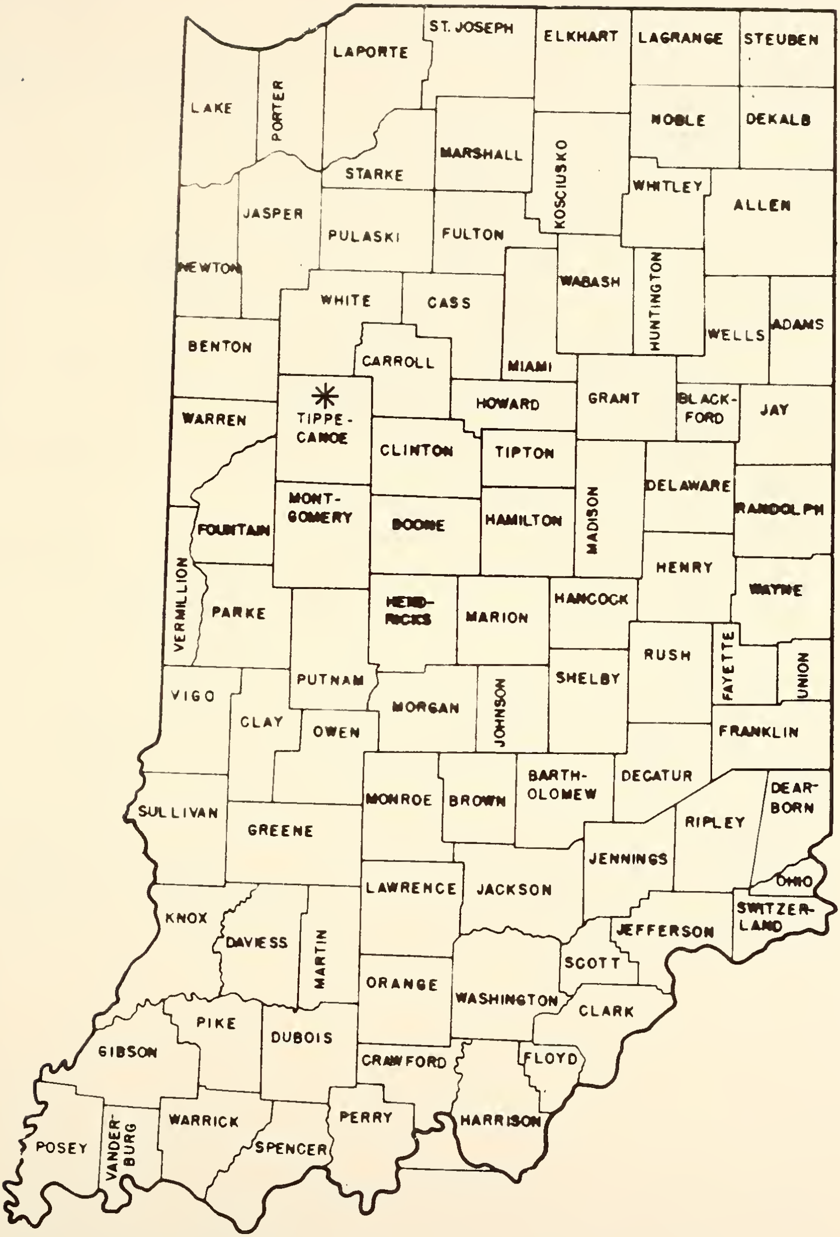


FIGURE 1. INDIANA COUNTY MAP

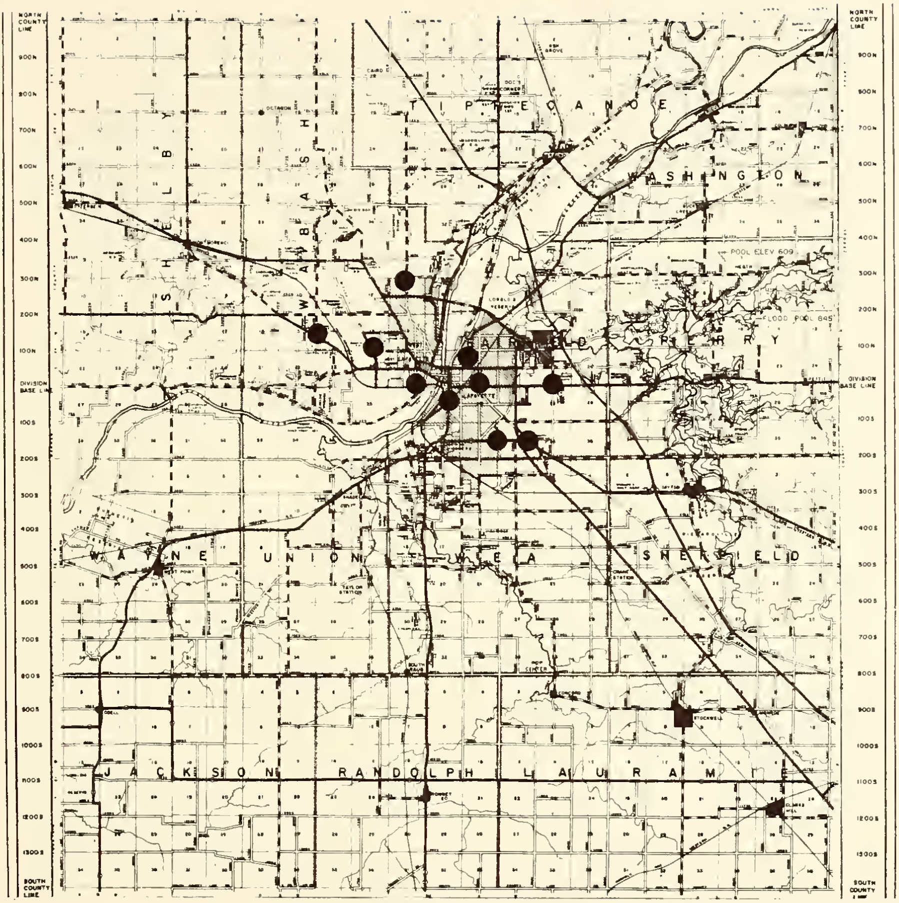


FIGURE 2. MAP OF TIPPECANOE COUNTY WITH RELATIVE LOCATIONS OF STUDY SITES

TABLE 1

SUMMARY CHARACTERISTICS OF STUDY LOCATIONS

| Location Number | Intersection | Type of Area | Presence of a Right-Turn Deceleration Lane | Total Weekday Volume ADT |
|---|---|---|---|---|
| 1 | S. R. 526 & West Stadium Avenue | Urban | Yes | 2,700 |
| 2 | S. R. 38 & K-Mart Shopping Center | Urban | Yes | 6,900 |
| 3 | S. R. 25 & Sequoya Road | Urban | Yes | 15,600 |
| 4 | S. R. 26 & County Route 350 East | Rural | No | 4,000 |
| 5 | Wood & Grant Streets | Urban | No | 6,400 |
| 6 | S. R. 26 & North 25th Street | Urban | No | 11,300 |
| 7 | 14th & Hartford Streets | Urban | No | 5,900 |
| 8 | S. R. 26 & County Route 300 West | Rural | No | 3,200 |
| 9 | S. R. 43 & Kossuth Street | Urban | No | 10,700 |
| 10 | North Salisbury & Kent Streets | Urban | No | 4,800 |

## Delay Data

The delays that were measured at the ten study locations were delays to through vehicles caused by right-turning vehicles during daylight-weekday hours, 6 A.M. to 6 P.M. As noted earlier, a 20-pen recorder was used to record data pertinent to through vehicle delays. This equipment was readily available and permitted a complete analysis of delay times.

Equipment used in the collection of delay data included:

1) a 20-pen recorder
2) relay boxes
3) road tubes
4) electrical wire
5) push button box
6) 12 volt battery
7) traffic counter

A typical field setup of this equipment is shown in Figure 3; and a diagram of the equipment connections is shown in Figure 4. A sample of a section of 20-pen recorder tape is shown in Figure 5. Although 20 pens (lines) were available only eight were used. Each one of the pens when actuated moves perpendicular to the parallel lines on the tape and leaves a blip. The pens that were used and the data shown by each are as follows:

1) pen 1 - identified a vehicle as a passenger or commercial vehicle
2) pen 2 - showed the number of right-turning vehicles in a queue

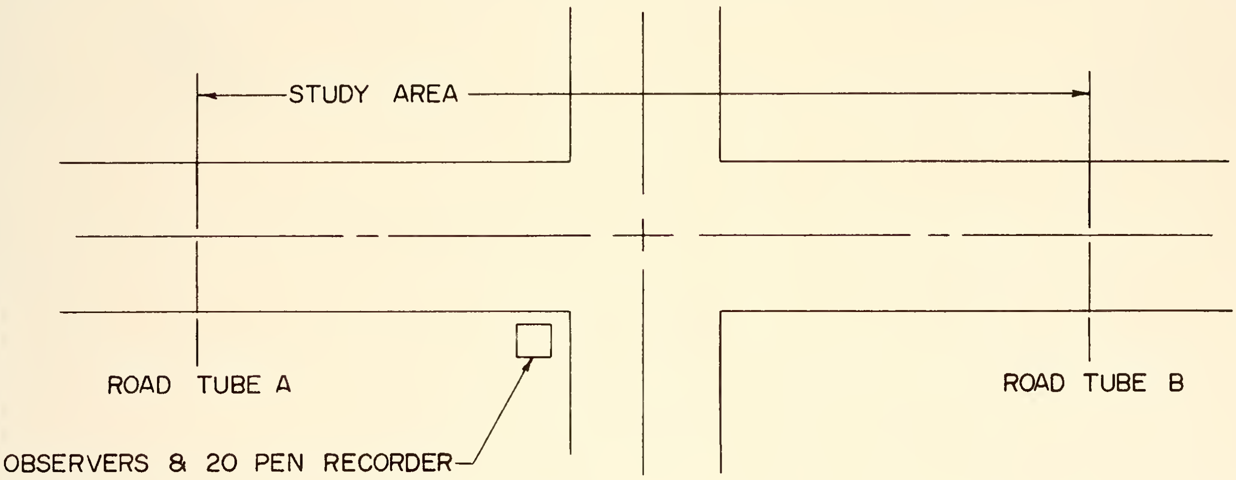


FIGURE 3- TYPICAL FIELD SETUP OF EQUIPMENT USED TO COLLECT DELAY TIMES

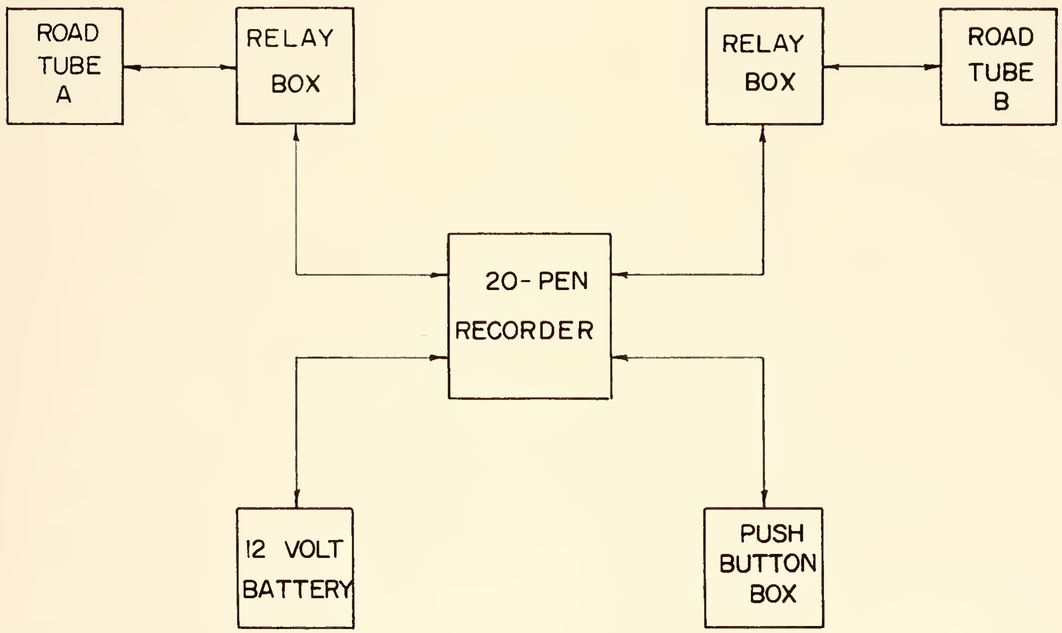


FIGURE 4 - LAYOUT OF EQUIPMENT USED TO COLLECT DELAY TIMES

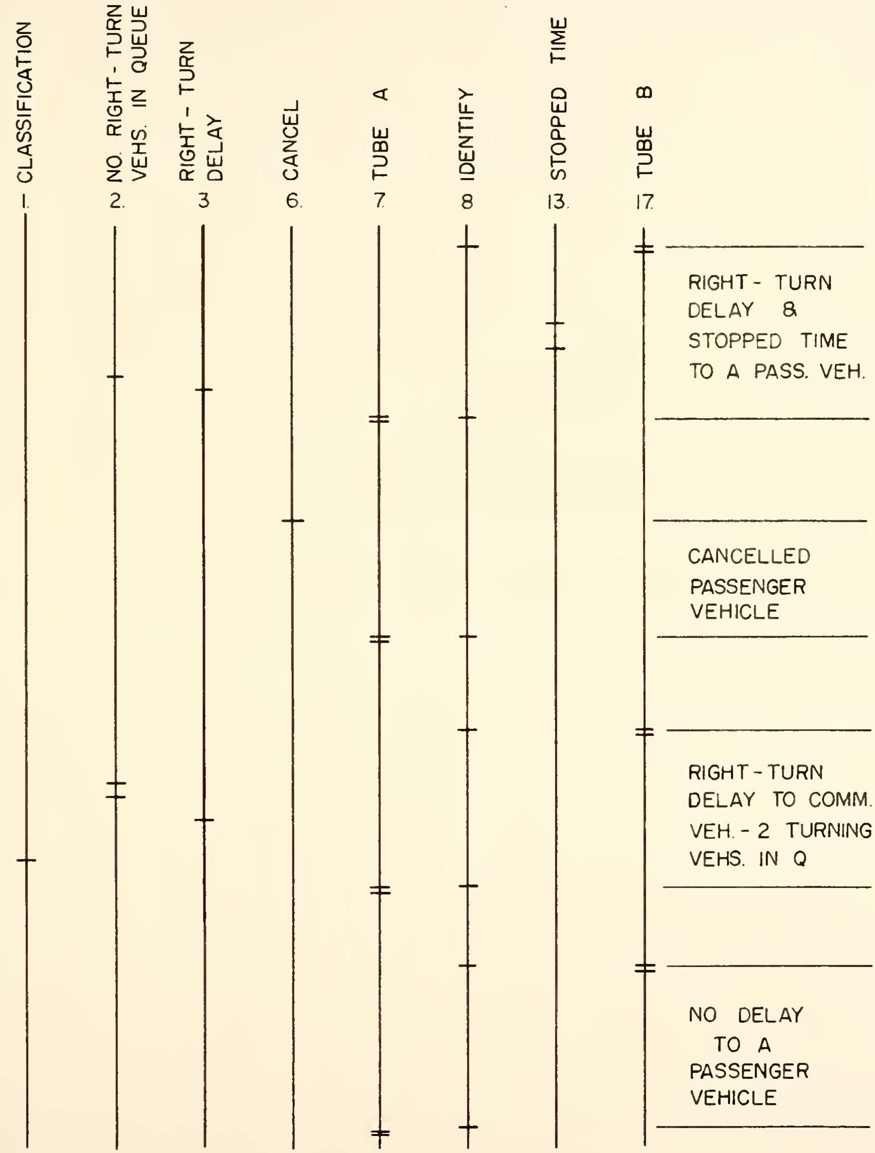

1. CLASSIFICATION
2. NO. RIGHT-TURN VEHS. IN QUEUE
3 RIGHT-TURN DELAY
6. CANCEL
7. TUBE A
8 IDENTIFY
13. STOPPED TIME
17. TUBE B
RIGHT-TURN DELAY & STOPPED TIME TO A PASS. VEH.
CANCELLED PASSENGER VEHICLE
RIGHT-TURN DELAY TO COMM. VEH. - 2 TURNING VEHS. IN Q
NO DELAY TO A PASSENGER VEHICLE

FIGURE 5 - SAMPLE SECTION OF A 20-PEN RECORDING TAPE

3) pen 3 - indicated a delay to a study vehicle caused by a right-turning vehicle
4) pen 6 - indicated a study vehicle was cancelled
5) pen 7 - noted when a vehicle crossed tube A
6) pen 8 - identified a vehicle as being a study vehicle
7) pen 13 - showed the stopped time to a study vehicle delayed by a right-turning vehicle
8) pen 17 - noted when a vehicle crossed tube B

When an approach vehicle crossed tube A an impulse was sent to the relay box and then through the wire to pen 7 on the recorder. If this were a study vehicle, then pen 8 was actuated to identify the blip on line 7 as a study vehicle. The first study vehicle for each period of operation was a selected approach vehicle that crossed tube A. As soon as this vehicle passed through the study area or was cancelled, the next approach vehicle to enter the study area was the next study vehicle. If the study vehicle went through the entire study area, it crossed tube B and caused a blip on line 17. Pen 8 was then actuated to identify this blip as the study vehicle leaving the study area. If a vehicle being studied did not pass through the entire study area, pen 6 was actuated to cancel the vehicle. While a study vehicle was passing through the study area, pen 3 was actuated if the vehicle was delayed by a right-turning vehicle. If a study vehicle was delayed by anything other than a right-turning vehicle, the study vehicle was cancelled by pen 6.

The study area was defined to be the distance between a point before an intersection or access point where a through vehicle was

influenced by a right-turning vehicle and a point after the intersection where a through vehicle had resumed its initial approach speed. This was the distance between road tubes A and B in the field. This distance varied from approximately 550 feet to 1050 feet because of differences in the approach speeds at the different study locations.

Two people were used at each field location. One observer operated the push button box which was connected to the 20-pen recorder, and the other observer counted the number of right turns and left turns in the approach traffic and classified each vehicle as passenger car or truck.

The data collected and the delays obtained are shown in Table 2.

The seconds of delay per hour to the approach through traffic in Table 2 were calculated from the observed delay to a portion of the hourly volume using the following formula:

$$SDH = V \cdot P \cdot T$$

where

SDH = seconds of delay per hour to the approach through traffic caused by right-turning vehicles

V = approach through traffic per hour

P = percentage of studied through vehicles delayed

T = difference in the means of the times of travel through the study area between the delayed and non-delayed vehicles for that portion of the through traffic for which delay was measured.

TABLE 2

DELAY DATA FOR STUDY LOCATIONS WITHOUT RIGHT-TURN DECELERATION LANES

| Site No. | Sample Number | Day & Time | SDH* | App. Vol. | App. Thru Vol. | Opposing Volume | Approach Capacity | Opposing Capacity | Non-delay Speed, fps | Delay Speed, fps | No. Rt. Turns | No. Lt. Turns | Studied Thru Vehs. Delayed | Total Obs. | Location, Rural or Urban | Approach Width, ft. | Approach Grade, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 4-1 | M 9:45-10:45 | 0 | 91 | 77 | 62 | 1550 | 1650 | 75.75 | 75.75 | 14 | 0 | 0 | 49 | 1 | 12.0 | 0 |
| 4 | 4-2 | M 10:45-11:45 | 0 | 102 | 90 | 108 | 1550 | 1650 | 76.14 | 76.14 | 10 | 2 | 0 | 52 | 1 | 12.0 | 0 |
| 4 | 4-3 | M 11:45-12:45 | 0 | 116 | 104 | 131 | 1550 | 1650 | 75.87 | 75.87 | 10 | 2 | 0 | 63 | 1 | 12.0 | 0 |
| 5 | 5-1 | M 10:45-11:45 | 0 | 130 | 74 | 166 | 1100 | 1000 | 36.08 | 36.08 | 52 | 5 | 0 | 42 | 0 | 10.0 | 0 |
| 5 | 5-2 | M 11:45-12:45 | 0 | 207 | 155 | 288 | 1100 | 1000 | 36.19 | 36.19 | 44 | 11 | 0 | 57 | 0 | 10.0 | 0 |
| 5 | 5-3 | M 12:45- 1:45 | 0 | 263 | 165 | 160 | 1100 | 1000 | 36.64 | 36.64 | 65 | 20 | 0 | 70 | 0 | 10.0 | 0 |
| 5 | 5-4 | Th 8:00- 9:00 | 18.3 | 244 | 114 | 128 | 1100 | 1000 | 37.39 | 33.57 | 49 | 30 | 5 | 113 | 0 | 10.0 | 0 |
| 5 | 5-5 | Th 9:00-10:00 | 6.4 | 136 | 86 | 115 | 1100 | 1000 | 37.67 | 34.70 | 28 | 13 | 3 | 81 | 0 | 10.0 | 0 |
| 5 | 5-6 | Th 10:00-11:00 | 13.3 | 129 | 64 | 128 | 1100 | 1000 | 37.14 | 24.01 | 36 | 11 | 1 | 79 | 0 | 10.0 | 0 |
| 5 | 5-7 | W 2:00- 3:00 | 5.4 | 140 | 82 | 181 | 1100 | 1000 | 37.21 | 34.89 | 37 | 11 | 3 | 77 | 0 | 10.0 | 0 |
| 5 | 5-8 | W 3:00- 4:00 | 12.7 | 156 | 90 | 166 | 1100 | 1000 | 37.68 | 35.16 | 53 | 4 | 6 | 78 | 0 | 10.0 | 0 |
| 5 | 5-9 | W 4:00- 5:00 | 40.2 | 240 | 121 | 430 | 1100 | 1000 | 37.48 | 33.99 | 92 | 7 | 12 | 109 | 0 | 10.0 | 0 |
| 6 | 6-1 | Tu 12:30- 1:30 | 62.8 | 351 | 293 | 358 | 1000 | 1300 | 40.22 | 34.47 | 34 | 46 | 8 | 103 | 0 | 12.0 | 0 |
| 6 | 6-2 | Tu 1:30- 2:30 | 18.9 | 311 | 235 | 309 | 1000 | 1300 | 41.27 | 37.39 | 30 | 50 | 5 | 115 | 0 | 12.0 | 0 |
| 6 | 6-3 | Tu 2:30- 3:30 | 63.8 | 337 | 246 | 361 | 1000 | 1300 | 41.84 | 32.69 | 23 | 55 | 5 | 98 | 0 | 12.0 | 0 |
| 6 | 6-4 | F 3:00- 4:00 | 135.1 | 356 | 242 | 407 | 1000 | 1300 | 42.69 | 31.54 | 58 | 75 | 9 | 109 | 0 | 12.0 | 0 |
| 6 | 6-5 | F 4:00- 5:00 | 106.0 | 514 | 345 | 473 | 1000 | 1300 | 44.18 | 31.58 | 36 | 103 | 6 | 146 | 0 | 12.0 | 0 |
| 6 | 6-6 | F 5:00- 6:00 | 71.9 | 425 | 291 | 458 | 1000 | 1300 | 43.60 | 33.28 | 37 | 89 | 6 | 140 | 0 | 12.0 | 0 |
| 6 | 6-7 | M 9:15-10:15 | 3.1 | 274 | 201 | 226 | 1000 | 1300 | 44.10 | 42.47 | 28 | 38 | 3 | 127 | 0 | 12.0 | 0 |
| 6 | 6-8 | M 10:15-11:15 | 54.0 | 303 | 228 | 271 | 1000 | 1300 | 44.90 | 34.52 | 30 | 41 | 6 | 125 | 0 | 12.0 | 0 |
| 6 | 6-9 | M 11:15-12:15 | 63.6 | 299 | 241 | 319 | 1000 | 1300 | 43.54 | 32.78 | 22 | 48 | 6 | 118 | 0 | 12.0 | 0 |
| 7 | 7-1 | W 11:30-12:30 | 30.9 | 186 | 113 | 156 | 1300 | 950 | 42.19 | 33.74 | 31 | 14 | 4 | 92 | 0 | 12.0 | 0 |
| 7 | 7-2 | W 12:30- 1:30 | 94.9 | 213 | 125 | 170 | 1300 | 950 | 40.66 | 32.38 | 58 | 16 | 9 | 82 | 0 | 12.0 | 0 |
| 8 | 8-1 | M 4:00- 5:00 | 262.6 | 250 | 136 | 26 | 1200 | 1650 | 66.39 | 47.19 | 95 | 0 | 22 | 105 | 1 | 10.5 | 0 |
| 8 | 8-2 | M 5:00- 6:00 | 403.3 | 323 | 200 | 39 | 1200 | 1650 | 68.10 | 49.61 | 146 | 0 | 29 | 116 | 1 | 10.5 | 0 |
| 8 | 8-3 | Th 1:15- 2:15 | 27.3 | 87 | 48 | 41 | 1200 | 1650 | 69.69 | 56.57 | 35 | 0 | 6 | 58 | 1 | 10.5 | 0 |
| 8 | 8-4 | Th 2:15- 3:15 | 44.4 | 97 | 49 | 49 | 1200 | 1650 | 73.76 | 46.34 | 52 | 0 | 4 | 64 | 1 | 10.5 | 0 |
| 8 | 8-5 | Th 3:15- 4:15 | 72.7 | 153 | 111 | 59 | 1200 | 1650 | 74.19 | 57.96 | 58 | 0 | 12 | 87 | 1 | 10.5 | 0 |
| 8 | 8-6 | Tu 10:00-11:00 | 13.0 | 67 | 28 | 30 | 1200 | 1650 | 71.93 | 52.08 | 38 | 0 | 2 | 50 | 1 | 10.5 | 0 |
| 8 | 8-7 | Tu 11:00-12:00 | 21.6 | 96 | 45 | 54 | 1200 | 1650 | 75.96 | 62.65 | 52 | 0 | 6 | 68 | 1 | 10.5 | 0 |
| 8 | 8-8 | Tu 12:00- 1:00 | 22.7 | 119 | 48 | 60 | 1200 | 1650 | 68.89 | 59.99 | 69 | 0 | 7 | 72 | 1 | 10.5 | 0 |
| 9 | 9-1 | W 11:00-12:00 | 50.2 | 322 | 243 | 348 | 1550 | 1150 | 41.59 | 39.12 | 33 | 14 | 11 | 82 | 0 | 14.0 | 8.3 |
| 9 | 9-2 | W 12:00- 1:00 | 1.3 | 344 | 273 | 354 | 1550 | 1150 | 43.40 | 42.97 | 24 | 24 | 2 | 87 | 0 | 14.0 | 8.3 |
| 10 | 10-1 | Th 4:00- 5:00 | 92.2 | 203 | 163 | 203 | 1100 | 1350 | 45.80 | 37.92 | 48 | 0 | 14 | 81 | 0 | 10.0 | 0 |
| 10 | 10-2 | Th 5:00- 6:00 | 104.4 | 255 | 201 | 121 | 1100 | 1350 | 46.28 | 37.90 | 52 | 0 | 16 | 108 | 0 | 10.0 | 0 |

*SDH = Seconds of delay per hour to the approach through traffic caused by right-turning vehicles.

Data for the three variables used to calculate delay were recorded on the 20-pen recorder tapes. The recorder was operated at a speed of six inches per minute. It was possible to calculate the time of every vehicle that traveled through the entire study area by knowing the speed of the recorder, the distance on the tape between a vehicle entering and leaving the study area, and the field distance of the study area. The through volume was calculated by multiplying the approach volume by a factor which was the number of through vehicles studied divided by the total number of study vehicles.

From the field data it was observed that at the sites having deceleration lanes delays incurred by through vehicles were extremely small. This is shown in Table 3. This finding is in agreement with the inference in the AASHO Policy Manual (1) mentioned in a previous section of this report. It was concluded, therefore, that for two lane, two-way highways carrying low to moderate volumes, right-turn deceleration lanes do eliminate almost all delay to through vehicles.

## Accident Data

The accident analysis was concerned with those accidents at the ten study locations occurring 1963 through 1969 which involved right-turning vehicles and through vehicles and which probably could have been prevented with the use of a deceleration lane. Such accidents were considered to be:

1) rear-end accidents resulting from a right-turning movement, and
2) sideswipe accidents involving a vehicle overtaking a right-turning vehicle

TABLE 3

DELAY DATA FOR STUDY LOCATIONS WITH RIGHT-TURN DECELERATION LANES

| Site No. | Sample Number | Day & Time | SDH* | App. Vol. | App. Thru Vol. | Opposing Volume | Approach Capacity | Opposing Capacity | Non-delay Speed, fps | Delay Speed, fps | No. Rt. Turns | No. Lt. Turns | Studied Thru Vehs. Delayed | Total Obs. | Location, Rural or Urban | Approach Width, ft. | Approach Grade, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1-1 | Tu 12:00- 1:00 | 0 | 120 | 53 | 68 | 2650 | 1100 | 57.81 | 57.81 | 65 | 0 | 0 | 86 | 0 | 12.0 | 4.2 |
| 1 | 1-2 | Tu 1:00- 2:00 | 0 | 93 | 44 | 59 | 2650 | 1100 | 59.05 | 59.05 | 50 | 0 | 0 | 68 | 0 | 12.0 | 4.2 |
| 1 | 1-3 | Tu 2:00- 3:00 | 0 | 74 | 44 | 51 | 2650 | 1100 | 55.35 | 55.35 | 36 | 0 | 0 | 59 | 0 | 12.0 | 4.2 |
| 2 | 2-1 | W 11:00-12:00 | 0 | 182 | 87 | 177 | 2000 | 1000 | 61.47 | 61.47 | 78 | 0 | 0 | 86 | 0 | 11.0 | 0 |
| 2 | 2-2 | W 12:00- 1:00 | 9.7 | 229 | 127 | 174 | 2000 | 1000 | 57.61 | 54.99 | 99 | 0 | 4 | 76 | 0 | 11.0 | 0 |
| 2 | 2-3 | W 1:00- 2:00 | 8.3 | 217 | 132 | 179 | 2000 | 1000 | 57.60 | 46.10 | 78 | 0 | 1 | 84 | 0 | 11.0 | 0 |
| 3 | 3-1 | F 11:00-12:00 | 5.9 | 448 | 361 | 374 | 2150 | 1100 | 53.68 | 49.60 | 53 | 25 | 1 | 118 | 0 | 11.0 | 0 |
| 3 | 3-2 | F 12:00- 1:00 | 0 | 554 | 372 | 511 | 2150 | 1100 | 52.45 | 52.45 | 77 | 41 | 0 | 134 | 0 | 11.0 | 0 |
| 3 | 3-3 | F 1:00- 2:00 | 0 | 389 | 310 | 365 | 2150 | 1100 | 55.20 | 55.20 | 32 | 33 | 0 | 114 | 0 | 11.0 | 0 |

*SDH = Seconds of delay per hour to the approach through traffic caused by right-turning vehicles.

The accident records of the Lafayette Police Department, the West Lafayette Police Department, and the Indiana State Police were studied. The information was taken from the standard investigating officer's accident report form.

Police records were studied for the seven year period 1963-1969. All the available records were studied to obtain the number of accidents that occurred and to determine if any accidents reported were of the two types considered as preventable by a right-turn deceleration lane.

The result of the accident data investigation is shown in Table 4. From this accident data, it was observed that at the sites having deceleration lanes there were no accidents involving a through vehicle and a right-turning vehicle. This finding is also in agreement with the inference in the AASHO Policy Manual (1) previously mentioned in this report. However, as Table 4 shows, a few accidents that involved a through vehicle and a right-turning vehicle did occur at all but one of the locations without deceleration lanes.

## TABLE 4

## ACCIDENT DATA*

| Location Number | Presence of a Right-Turn Deceleration Lane | Total Weekday Volume ADT | Total Number of Accidents | Total Number of Preventable Accidents** | Damages from Preventable Accidents |
|---|---|---|---|---|---|
| 1 | Yes | 2,700 | 1 | 0 | $ 0 |
| 2 | Yes | 6,900 | 12 | 0 | $ 0 |
| 3 | Yes | 15,600 | 39 | 0 | $ 0 |
| 4 | No | 4,000 | 13 | 1 | $500 |
| 5 | No | 6,400 | 50 | 1 | $200 |
| 6 | No | 11,300 | 20 | 1 | $850 |
| 7 | No | 5,900 | 64 | 2 | $300 |
| 8 | No | 3,200 | 1 | 1 | $250 |
| 9 | No | 10,700 | 73 | 3 | $850 |
| 10 | No | 4,800 | 0 | 0 | $ 0 |

*Accident data for the years 1963 through 1969.

**Preventable accidents are accidents considered to be preventable with a right-turn deceleration lane.

# ANALYSIS

## Regression Technique

An equation that relates a dependent variable to a number of independent variables is often called a regression equation (5,7). A regression analysis is, therefore, a technique that tries to relate some dependent variable to some independent variables by means of an equation. A linear regression analysis tries to find a linear equation. The linear regression equation can be of the form:

$$\hat{Y} = B_o + B_1X_1 + B_2X_2 + \ldots\ldots + B_nX_n$$

where $\hat{Y}$ is the predicted value of the dependent variable Y for the given values of the independent variables $X_1$ and $X_2$. $B_o$ is the Y-intercept and $B_1$ and $B_2$ are the partial regression coefficients which tell how a unit change in $X_1$ or $X_2$, respectively, would change $\hat{Y}$, provided all the other independent variables were held constant.

In using a linear regression equation, one assumes that this type of equation is valid for the data obtained. Various tests are available to evaluate the validity of this assumption.

The method used to determine the regression equation was the stepwise regression procedure; this procedure also provides pertinent data from which an examination of the regression equation can be made. This procedure enters into the regression equation the independent variable most highly correlated with the dependent variable. The next independent variable to enter is the one with the highest

partial correlation with the dependent variable, taking into account the previously entered independent variables in the regression equation. At each stage the variables in the equation are examined. An independent variable which may have been the best variable to enter at a previous stage may be dropped from the equation at a later stage because of its relationships with other variables in the equation. This evaluation is accomplished by checking the partial F-value of each independent variable in the equation at any stage against a preselected F-value. This partial F-value shows the contribution of a variable to the equation as though it had been the last variable entered. If the partial F-value is less than the preselected F-value, the variable is dropped from the equation because it does not make a significant contribution to the equation. This process continues until no more variables enter or leave the equation.

## Delay Times

The dependent variable being predicted in this regression analysis is the seconds of delay per hour (SDH) to the approach through traffic caused by right-turning vehicles. The independent variables are the variables used to predict the delay.

The regression analysis was performed on a CDC 6500 computer with the BMD2R (8) program. The BMD2R program is a computer package that performs the stepwise regression analysis. The analyses reported in this section were performed at an $\alpha$-level of 0.05.

The independent variables that were considered initially (Stage 1) are shown in Table 5. The means and standard deviations are shown in

### TABLE 5

### INDEPENDENT VARIABLES - DELAY ANALYSIS, STAGE ONE

| Number | Variable Description |
|---|---|
| 2 | Grade of Approach, Percentage |
| 3 | Width of Approach, Feet |
| 4 | Average Speed Through the Study Area for a Non-Delayed Through Vehicle, Feet Per Second |
| 5 | Average Speed Through the Study Area for a Delayed Through Vehicle, Feet Per Second |
| 6 | Approach Volume, Vehicles Per Hour |
| 7 | Opposing Volume, Vehicles Per Hour |
| 8 | Right Turns in the Approach Volume, Percentage |
| 9 | Left Turns in the Approach Volume, Percentage |
| 10 | Approach Through Vehicles Delayed, Percentage |
| 11 | Ratio of Approach Volume to Approach Capacity |
| 12 | Ratio of Opposing Volume to Opposing Capacity |
| 13 | Total Volume, Vehicles Per Hour |
| 14 | Location, Rural or Urban |

## TABLE 6

## MEANS AND STANDARD DEVIATIONS OF THE INDEPENDENT VARIABLES - DELAY ANALYSIS, STAGE ONE

| Variable | Mean | Standard Deviation |
|---|---|---|
| 2 | 0.47429 | 1.95468 |
| 3 | 11.14286 | 1.14128 |
| 4 | 50.72086 | 15.25221 |
| 5 | 42.82714 | 13.64846 |
| 6 | 223.97143 | 109.30139 |
| 7 | 198.71429 | 136.12161 |
| 8 | 24.62029 | 16.03329 |
| 9 | 7.32657 | 7.52200 |
| 10 | 11.16057 | 10.15163 |
| 11 | 20.23086 | 11.39095 |
| 12 | 16.38257 | 11.42944 |
| 13 | 422.68571 | 232.72235 |
| 14 | 0.31429 | 0.47101 |

## TABLE 7

## CORRELATION MATRIX OF STAGE ONE VARIABLES

CORRELATION MATRIX

| VARIABLE NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.000 | -.090 | -.045 | .173 | -.073 | .389 | -.074 | .165 | -.088 | .768 |
| 2 |  | 1.000 | .625 | -.135 | -.033 | .249 | .279 | -.249 | -.064 | -.021 |
| 3 |  |  | 1.000 | -.019 | .075 | .485 | .503 | -.639 | .328 | -.245 |
| 4 |  |  |  | 1.000 | .892 | -.491 | -.630 | .459 | -.595 | .303 |
| 5 |  |  |  |  | 1.000 | -.537 | -.555 | .246 | -.581 | .061 |
| 6 |  |  |  |  |  | 1.000 | .796 | -.589 | .683 | .036 |
| 7 |  |  |  |  |  |  | 1.000 | -.645 | .631 | -.295 |
| 8 |  |  |  |  |  |  |  | 1.000 | -.631 | .538 |
| 9 |  |  |  |  |  |  |  |  | 1.000 | -.412 |
| 10 |  |  |  |  |  |  |  |  |  | 1.000 |

| VARIABLE NUMBER | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|
| 1 | .339 | -.119 | .139 | .206 | .085 |
| 2 | .027 | .298 | .280 | -.167 | .172 |
| 3 | .349 | .417 | .522 | -.141 | .408 |
| 4 | -.511 | -.723 | -.599 | .975 | -.681 |
| 5 | -.579 | -.627 | -.577 | .863 | -.656 |
| 6 | .966 | .731 | .935 | -.550 | .902 |
| 7 | .794 | .977 | .959 | -.700 | .961 |
| 8 | -.556 | -.586 | -.654 | .572 | -.624 |
| 9 | .757 | .587 | .690 | -.639 | .732 |
| 10 | -.023 | -.293 | -.155 | .362 | -.199 |
| 11 | 1.000 | .720 | .918 | -.566 | .916 |
| 12 |  | 1.000 | .915 | -.766 | .937 |
| 13 |  |  | 1.000 | -.668 | .986 |
| 14 |  |  |  | 1.000 | -.735 |
| 15 |  |  |  |  | 1.000 |

Table 6, and the correlation matrix of all the variables is shown in Table 7. The equation resulting from this analysis was:

$$SDH = -64.7 + 0.58\ X_6 - 0.31\ X_7 + 4.62\ X_{10}$$

these variables are as numbered in Table 5.

This equation explained 79 percent of the variability in the data. In this equation, the percentage of through vehicles delayed (variable 10) explained 59 percent of the variability in the data used to predict SDH. The approach volume and the opposing volume (variables 6 and 7) each explained an additional 13 percent and 7 percent, respectively, of this variability when they entered the equation.

In a second analysis (Stage 2) variables 6, 7, 11, and 12, as numbered in Table 5, were deleted. These variables were replaced with the total volume and the ratio of total volume to total capacity. This was done because total volume was very highly correlated with the approach volume and the opposing volume, 0.935 and 0.959 respectively.

The independent variables considered in this stage are shown in Table 8. The means and standard deviations are shown in Table 9, and the correlation matrix of all the variables is shown in Table 10. The equation resulting from this analysis was:

$$SDH = 13.4 - 1.75\ X_8 + 7.57\ X_{10}$$

these variables are as numbered in Table 8.

This equation explained 68 percent of the variability in the data. In this equation, the percentage of through vehicles delayed (variable 10) explained 59 percent of the variability in the data used to predict SDH. The percentage of right turns in the approach volume

TABLE 8

INDEPENDENT VARIABLES - DELAY ANALYSIS, STAGE TWO

| Number | Variable Description |
|---|---|
| 2 | Grade of Approach, Percentage |
| 3 | Width of Approach, Feet |
| 4 | Average Speed Through the Study Area for a Non-Delayed Through Vehicle, Feet Per Second |
| 5 | Average Speed Through the Study Area for a Delayed Through Vehicle, Feet Per Second |
| 8 | Right Turns in the Approach Volume, Percentage |
| 9 | Left Turns in the Approach Volume, Percentage |
| 10 | Approach Through Vehicles Delayed Percentage |
| 13 | Total Volume, Vehicles Per Hour |
| 14 | Location, Rural or Urban |
| 15 | Ratio of Total Volume to Total Capacity |

## TABLE 9

## MEANS AND STANDARD DEVIATIONS OF THE INDEPENDENT VARIABLES - DELAY ANALYSIS, STAGE TWO

| Variable | Mean | Standard Deviation |
|---|---|---|
| 2 | 0.47429 | 1.95468 |
| 3 | 11.14286 | 1.14128 |
| 4 | 50.72086 | 15.25221 |
| 5 | 42.82714 | 13.64846 |
| 8 | 24.62029 | 16.03329 |
| 9 | 7.32657 | 7.52200 |
| 10 | 11.16057 | 10.15163 |
| 13 | 422.68571 | 232.72235 |
| 14 | 0.31429 | 0.47101 |
| 15 | 17.90800 | 10.48885 |

## TABLE 10

## CORRELATION MATRIX OF STAGE TWO VARIABLES

CORRELATION MATRIX

| VARIABLE NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.000 | -.090 | -.045 | .173 | -.073 | .389 | -.074 | .165 | -.088 | .768 |
| 2 | | 1.000 | .625 | -.135 | -.033 | .249 | .279 | -.249 | -.064 | -.021 |
| 3 | | | 1.000 | -.019 | .075 | .485 | .503 | -.639 | .328 | -.245 |
| 4 | | | | 1.000 | .892 | -.491 | -.630 | .459 | -.595 | .303 |
| 5 | | | | | 1.000 | -.537 | -.555 | .246 | -.581 | .061 |
| 6 | | | | | | 1.000 | .796 | -.589 | .683 | .036 |
| 7 | | | | | | | 1.000 | -.645 | .631 | -.295 |
| 8 | | | | | | | | 1.000 | -.631 | .538 |
| 9 | | | | | | | | | 1.000 | -.412 |
| 10 | | | | | | | | | | 1.000 |

| VARIABLE NUMBER | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|
| 1 | .339 | -.119 | .139 | .206 | .085 |
| 2 | .027 | .298 | .280 | -.167 | .172 |
| 3 | .349 | .417 | .522 | -.141 | .408 |
| 4 | -.511 | -.723 | -.599 | .975 | -.681 |
| 5 | -.579 | -.627 | -.577 | .863 | -.656 |
| 6 | .966 | .731 | .935 | -.550 | .902 |
| 7 | .794 | .977 | .959 | -.700 | .961 |
| 8 | -.556 | -.586 | -.654 | .572 | -.624 |
| 9 | .757 | .587 | .690 | -.639 | .732 |
| 10 | -.023 | -.293 | -.155 | .362 | -.199 |
| 11 | 1.000 | .720 | .918 | -.566 | .916 |
| 12 | | 1.000 | .915 | -.766 | .937 |
| 13 | | | 1.000 | -.668 | .986 |
| 14 | | | | 1.000 | -.735 |
| 15 | | | | | 1.000 |

(variable 8) explained an additional 9 percent of this variability when it entered the equation. Since the percentage of through vehicles delayed (variable 10) explained 59 percent of the variability, an attempt to predict this variable was made. The results, however, were not considered adequate and the attempt was discontinued.

In the third and final stage, variable 10, as numbered in Table 8, was deleted because it was difficult to predict and therefore impractical of use in a prediction equation. The percentage of right turns in the approach volume (variable 8) was also deleted; to be replaced with the number of right turns in the approach volume. Variables 2, 3, 14,and 15, as numbered in Table 8, were also deleted, because they did not contribute significantly to the previous regression equations.

The independent variables used in this stage are shown in Table 11. The means and standard deviations are shown in Table 12, and the correlation matrix of all the variables is shown in Table 13. The best equation resulting from this analysis (Stage 3) was:

$$SDH = -219.0 + 2.05\ X_5 + 0.37\ X_2 + 1.94\ X_6$$

these variables are as numbered in Table 11.

This equation explained 76 percent of the variability in the data. In this equation, the number of right turns (variable 5) explained 56 percent of the variability in the data used to predict SDH. The approach volume and the mean speed of the non-delayed through vehicles (variables 2 and 6) each explained an additional 10 percent of this variability when they entered the equation. Thus, it can be seen that the single most important variable in predicting SDH in this equation

## TABLE 11

## INDEPENDENT VARIABLES - DELAY ANALYSIS, STAGE THREE

| Number | Variable Description |
|---|---|
| 2 | Approach Volume, Vehicles Per Hour |
| 3 | Approach Through Volume, Vehicles Per Hour |
| 4 | Total Volume, Vehicles Per Hour |
| 5 | Number of Right-Turning Vehicles in Approach Direction Per Hour |
| 6 | Average Speed Through the Study Area for a Non-Delayed Through Vehicle, Feet Per Second |
| 7 | Difference Between the Non-Delay Speed and the Delay Speed, Feet Per Second |

## TABLE 12

## MEANS AND STANDARD DEVIATIONS OF THE INDEPENDENT VARIABLES - DELAY ANALYSIS, STAGE THREE

| Variable | Mean | Standard Deviation |
|---|---|---|
| 2 | 223.97143 | 109.30139 |
| 3 | 152.20000 | 85.51876 |
| 4 | 422.68571 | 232.72235 |
| 5 | 45.11429 | 26.27431 |
| 6 | 50.72086 | 15.25221 |
| 7 | 7.89371 | 6.88846 |

# TABLE 13

## CORRELATION MATRIX OF STAGE THREE VARIABLES

CORRELATION MATRIX

| VARIABLE NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 1.000 | .389 | .297 | .139 | .748 | .173 | .528 |
| 2 | | 1.000 | .961 | .935 | .098 | -.491 | -.024 |
| 3 | | | 1.000 | .922 | -.077 | -.447 | -.168 |
| 4 | | | | 1.000 | -.081 | -.599 | -.183 |
| 5 | | | | | 1.000 | .079 | .402 |
| 6 | | | | | | 1.000 | .446 |
| 7 | | | | | | | 1.000 |

is the number of right-turning vehicles in the approach traffic, but the approach volume and the mean speed of the non-delayed through vehicles also made important contributions to the result.

This equation was selected as the best of all the equations from all stages of the analysis because the independent variables have a logical connection with the dependent variable and because the independent variables can be easily obtained.

In the Stage 1 and Stage 2 analyses, it was found that the grade of the study area and the width of the approach roadway did not contribute significantly to the predicting equations. The range of grades was 0 percent to 8 percent, and the range of the approach widths was 10 feet to 14 feet.

Although two of the locations in this analysis were rural, the type of location, rural or urban, was not significant in the equation. The characteristics of through vehicles interacting with right-turning vehicles were observed as being similar at access points and at intersections; therefore, the results of this analysis, although developed from data taken at intersections, should also be useful at access points.

It is important to note that it becomes risky to predict a Y-value (SDH) from some given X-values when X-values outside the range of the X-values used in obtaining the regression equation are used, unless one is reasonably certain that the regression equation exists for a wider range of X-values. In the selected regression equation the X-variables are the approach volume, the number of right-turns in the approach traffic, and the mean speed of the non-delayed

through vehicles. Their approximate ranges were, respectively, 50 to 550 vehicles per hour, 10 to 150 right-turns per hour, and 37 to 81 feet per second (25 to 55 miles per hour).

## Accidents

It was originally hoped that the same type of regression analysis could be applied to the accident data, but since the number of accidents considered preventable with the use of a right-turn deceleration lane were very few at the seven study sites without deceleration lanes, it was not possible to use this analysis technique.

Safety is an important aspect of today's highway design. One of the main objectives of the traffic engineer is to provide safer highways. An economic analysis is frequently performed to see if a safety feature should be included in the design. If the safety feature is economical it is usually included. In such an economic analysis, however, it is difficult to include all benefits at a dollar value. Collision costs are often available or can be estimated, but it is very hard to evaluate the cost of injuries, or the value of a person's life, or the social costs resulting from accidents.

Although it was found that accidents involving a through vehicle and a right-turning vehicle do occur at locations without deceleration lanes (Table 4), it was not possible to accurately evaluate economic benefits that would accrue from a reduction in the number of these accidents.

As stated previously, there were no accidents involving a through vehicle and a right-turning vehicle at the three sites with deceleration

lanes, but at the seven sites without deceleration lanes there were a total of nine such accidents, property damage only occurring. The total collision costs of these accidents were $2950; $420 per site for the seven year period 1963 through 1969, or $60 a year per site. As stated above, however, the number of accidents at a site were very few and the damage resulting was quite variable, thus precluding development of an accurate per site value.

A reduction in the number of accidents, however, should be considered as an important factor in marginal situations where benefits from less delay do not economically justify the construction of a right-turn deceleration lane.

# AN ECONOMIC WARRANT

## Development

In developing an economic warrant for the construction of a right-turn deceleration lane, an evaluation of the economic value of the major benefits to be obtained from such a lane - reduced delays to through vehicles and an increase in safety - was necessary. In addition, a determination of the annual costs of constructing, operating and maintaining such a deceleration lane had to be determined. It is proposed that when such annual dollar benefits equal or exceed such annual dollar costs, an economic warrant for construction of a right-turn deceleration lane would exist.

A regression equation was developed that predicts the seconds of delay per hour to the approach through traffic; however, it was not possible to develop a similar equation for the prediction of the reduction in accidents that could be expected from construction of a right-turn deceleration lane. Therefore, an economic warrant using only benefits from the reduction in delay is proposed, with consideration of improvement in safety relegated to an additional supporting factor status.

Savings, economic benefits, from a reduction in delays can be divided into two parts: (1) time costs, and (2) operating costs. These two parts can be divided further into passenger vehicle and commercial vehicle costs. Operating costs also vary with different speeds.

Several sources (2, 4, 6, 9) were consulted for determining time value and operating costs. The value of time and the operating costs developed from these sources and used in this research are shown in Table 14. The cost for constructing a deceleration lane in Indiana was determined to be $5.50 per square yard for a flexible pavement where the shoulder of the highway is available for such construction. This is the typical situation where a deceleration lane is to be added to an existing highway of rural design.

## Application

The application of the economic warrant consists of comparing the savings from a reduction in delay with the costs of constructing, operating and maintaining a deceleration lane.

The proper design for a deceleration lane is given in the AASHO Policy Manual (1). It includes a taper and a full width lane. This design is shown in Figure 6. The length of the deceleration lane is governed by the average running speed on the approach and a design speed of fifteen miles per hour for the right-turning movement.

In the two examples that follow, the highways were of rural design and adequate shoulder and right-of-way existed; if these conditions do not exist, then the cost of acquiring right-of-way and/or any additional costs of construction must be added to the costs of the deceleration lane.

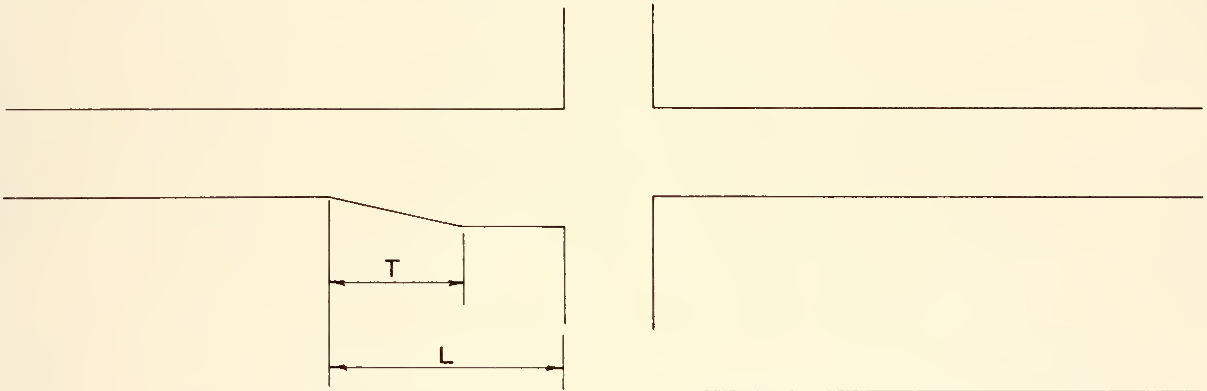
### Example 1

The location used in this example is shown in Figure 17; this is a rural location with a speed limit of 50 miles per hour.

## TABLE 14

## 1970 VALUES USED TO CALCULATE THE HOURLY DELAY COST

| Speed, mph | Passenger Vehicle Time Value | Passenger Vehicle Operating Costs | Commercial Vehicle Time Value | Commercial Vehicle Operating Costs |
|---|---|---|---|---|
| 30 | $1.60 | $0.55 | $2.70 | $0.55 |
| 40 | $1.60 | $0.75 | $2.70 | $0.80 |
| 50 | $1.60 | $1.05 | $2.70 | $1.20 |



| DESIGN SPEED M.P.H. | TURNING MOVEMENT SPEED M.P.H. | L | T |
|---|---|---|---|
| 30 | 15 | 185' | 145' |
| 40 | 15 | 295' | 190' |
| 50 | 15 | 405' | 230' |

FIGURE 6- PROPER DESIGN (1) OF A RIGHT-TURN DECELERATION LANE

The 1969 values of the variables determined in this study and used to predict the delay (SDH) were:

Number of right turns = 146 per hour

Approach volume = 323 vehicles per hour

Mean speed of non-delayed through vehicles = 68 feet per second (46 miles per hour)

The resulting value of SDH was:

SDH = 332 seconds of delay per hour to the approach through traffic.

The economic analysis performed to see when the benefits from a right-turn deceleration lane would repay the costs at this location is shown in Table 15. The analysis was performed for two different analysis periods, 5 years and 10 years. Two different length years were also used to expand SDH to the number of hours of delay per year. A year of 260 days, the number of work days, and a year of 365 days were used. Using 365 days a year assumes that delays on weekends will be at least as great as the delays recorded in the field on weekdays.

The economic analysis showed that the costs of a deceleration lane would be repaid within a five year period of 260 days per year using the 1969 values of the variables. The values of the variables will probably increase during the analysis period; therefore, a higher average value of the variables, which would result in higher economic benefits, could have been used for the analysis.

### Example 2

The location used in this example is shown in Figure 19; this is of rural design with a speed limit of 30 miles per hour. The 1969

## TABLE 15

## ECONOMIC ANALYSIS - EXAMPLE 1

### DELAY

| SDH | Hourly delay for a 260 day year | Hourly delay for a 365 day year |
|---|---|---|
| 332 | 288 | 404 |

### BENEFITS FROM LESS DELAY*

| Hourly | Total for a 260 day year | Total for a 365 day year |
|---|---|---|
| \$2.62 | \$755 | \$1058 |

### TOTAL COSTS OF A RIGHT-TURN DECELERATION LANE**

| Annually for a 5 year period | Annually for a 10 year period |
|---|---|
| \$580 | \$330 |

### GENERAL MODEL

$$\text{Benefits} = \frac{Z\ (12)}{3600}\ (\text{SDH})\ (\$2.62)$$

where SDH = seconds of delay per hour to the approach through traffic caused by right-turning vehicles

z = the number of days per year (260 or 365)

$$\text{Costs} = [\, I\ (\text{crf} - 6\% - n)\,]\ (1.15)$$

where I = initial costs

crf - 6 - n = capital recovery factor at 6% for n years.

---

*Traffic composed of 10 percent commercial vehicles

**Construction costs; 6 percent interest costs; and maintenance and operational costs of 15 percent of the annual capital costs.

values of the variables determined in this study and used to predict the delay (SDH) were:

Number of right turns = 48 per hour

Approach volume = 203 vehicles per hour

Mean speed of non-delayed through vehicles = 46 feet per second (31 miles per hour)

The resulting value of SDH was:

SDH = 43 seconds of delay per hour to the approach through traffic.

The economic analysis performed to see when the benefits from a right-turn deceleration lane would repay the costs at this location is shown in Table 16. The analysis was performed for the same analysis periods as in the previous example. In this example an annual increase of three percent was assumed to take place during the analysis periods for the number of right turns and the approach volume.

The economic analysis showed that the costs of a deceleration lane would be repaid within a ten year period, but for a five year period the benefits from a deceleration lane did not equal the costs of a deceleration lane. However, only benefits from a reduction in delays for the daylight hours, 6 A.M. to 6 P.M., were included. Consideration of the savings from a reduction in night time delays and from fewer accidents would probably provide sufficient benefits to repay the costs of a deceleration lane within a five year period for this example.

In the previous two examples, the economic analysis was performed for analysis periods of five years and ten years. A ten year life

TABLE 16

ECONOMIC ANALYSIS - EXAMPLE 2

AVERAGE DELAY FOR THE INDICATED TIME PERIOD

| | SDH | Hourly delay for a 260 day year | Hourly delay for a 365 day year |
|---|---|---|---|
| 1969-1974 | 57 | 49 | 69 |
| 1969-1979 | 75 | 65 | 91 |

BENEFITS FROM LESS DELAY FOR THE INDICATED TIME PERIOD*

| | Hourly | Total for a 260 day year | Total for a 365 day year |
|---|---|---|---|
| 1969-1974 | $2.27 | $112 | $157 |
| 1969-1979 | $2.27 | $148 | $207 |

TOTAL COSTS OF A RIGHT-TURN DECELERATION LANE**

| Annually for a 5 year period | Annually for a 10 year period |
|---|---|
| $225 | $130 |

---

*Traffic composed of 10 percent commercial vehicles.

**Construction costs; 6 percent interest costs; and maintenance and operational costs of 15 percent of the annual capital costs.

for a deceleration lane is probably less than actually can be expected. The annual costs, therefore, of a deceleration lane would probably be lower than calculated in the two examples. The results of these examples, however, illustrate the short periods of time within which benefits often will repay the costs of a deceleration lane.

In the two previous examples, SDH was calculated by using the developed predicting equation. After calculating SDH, it was then possible to proceed with an economic analysis and compare the benefits with the costs of a deceleration lane. In order to facilitate the use of an economic warrant, three charts (Figures 7, 8, and 9) were prepared. These charts show the conditions under which the benefits will repay the costs of a deceleration lane for several analysis periods.

These charts were prepared for the three speeds of 30, 40, and 50 miles per hour. To determine a value for benefits it was assumed that the traffic was composed of 10 percent commercial vehicles. To use the charts, three variables must be known; (1) the speed of vehicles on the approach (design speed, speed limit, or average speed of highway) and this must be approximately 30, 40, or 50 miles per hour, (2) the approach volume in vehicles per hour, and (3) the number of right turns per hour in the approach traffic. The values of the approach volume and number of right turns should be average values that occur during the daylight hours, 6 A.M. to 6 P.M.

The construction costs used in preparing these charts were $5.50 per square yard for a rural deceleration lane of AASHO minimum design (1) on a location with adequate shoulders and right-of-way, 6 percent

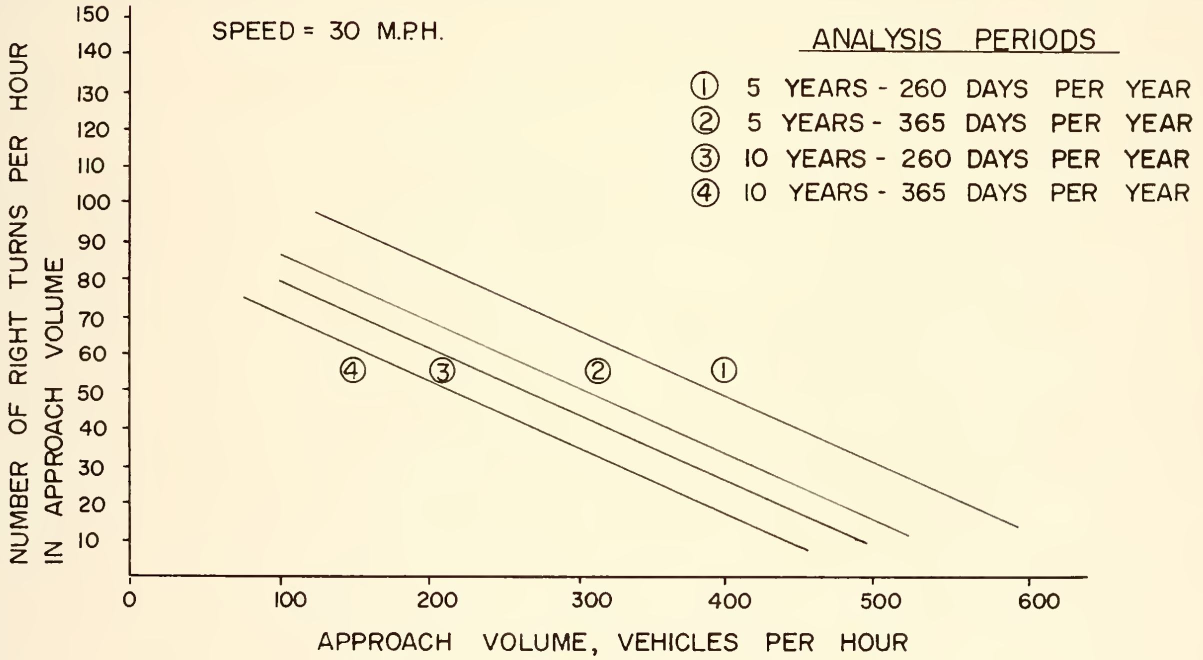


FIGURE 7 - A CHART FOR DETERMINING THE ECONOMIC FEASIBILITY OF A RIGHT - TURN DECELERATION LANE

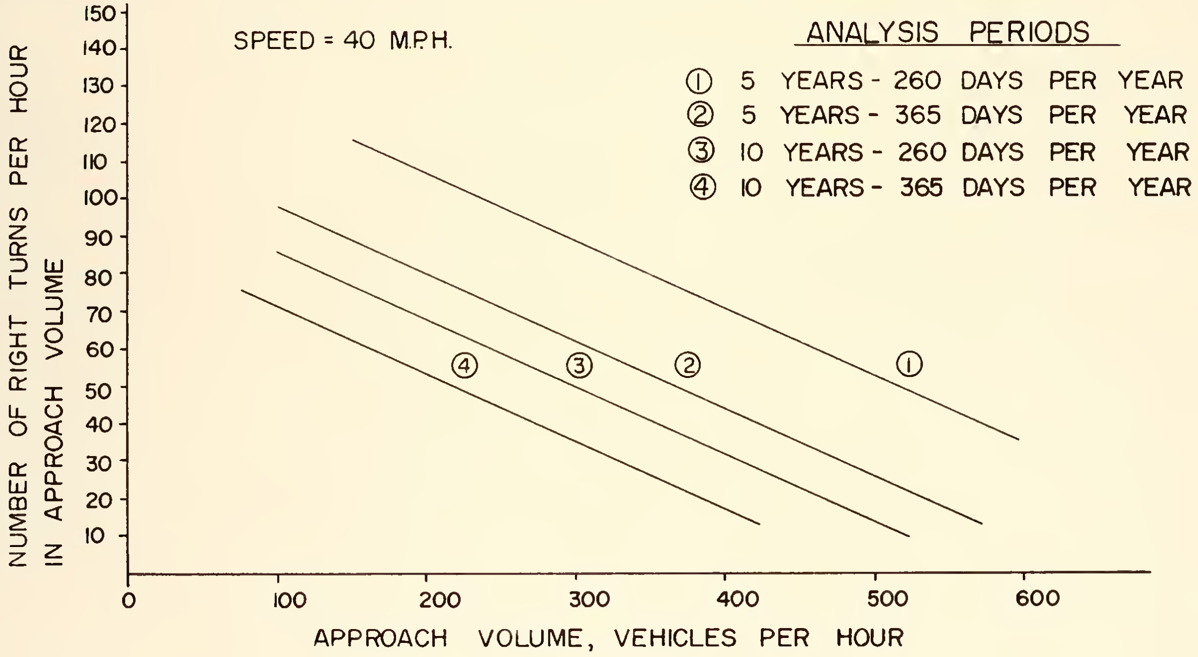


FIGURE 8 - A CHART FOR DETERMINING THE ECONOMIC FEASIBILITY OF A RIGHT-TURN DECELERATION LANE

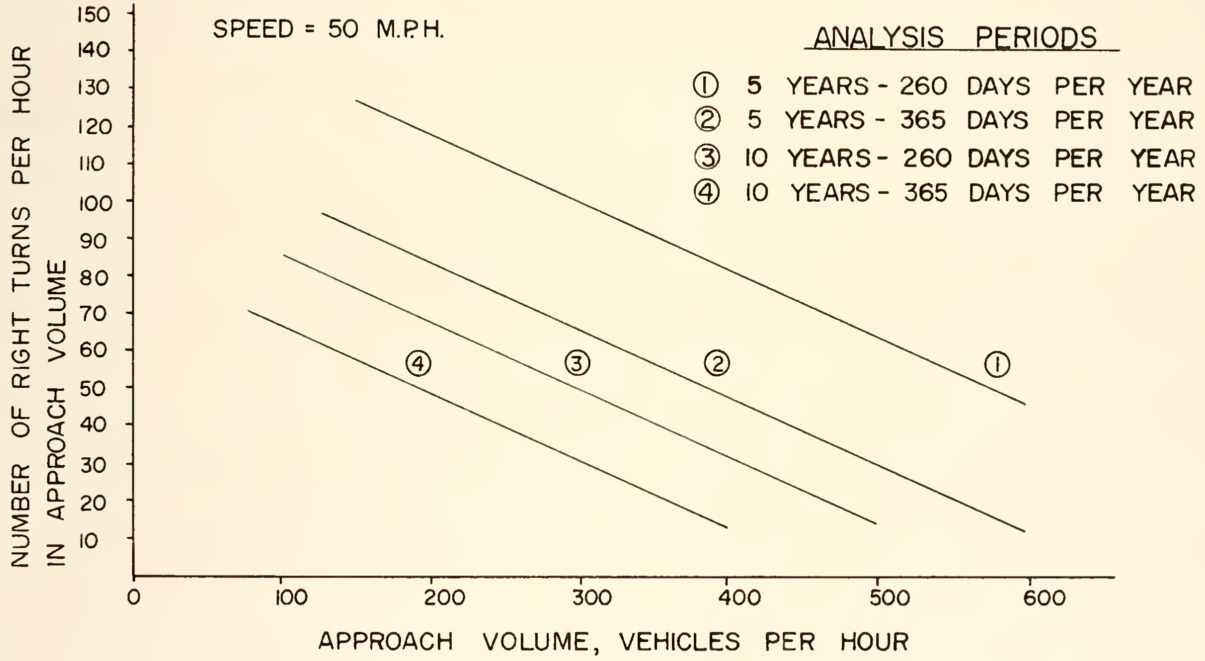


FIGURE 9 - A CHART FOR DETERMINING THE ECONOMIC FEASIBILITY OF A RIGHT - TURN DECELERATION LANE

interest, and an annual maintenance and operational cost of 15 percent of the annual capital costs.

On the charts, points which result from specific values for approach volume and number of right turns and which lie in the area above or to the right of a line representing a specified analysis period, indicate that the benefits will repay the costs of a deceleration lane within the specified analysis period. Conversely, if the resulting point lies in the area below or to the left of such a line, the benefits will not repay the costs of a deceleration lane within the specified analysis period. However, it is important to note that this last interpretation does not necessarily mean that it is not economical to construct a deceleration lane. The estimated service life of the deceleration lane should be used as the period of time over which to calculate the annual costs, if a true economic analysis is desired.

To illustrate the use of the charts, the two previous examples are presented again.

Example 1

Number of right turns = 146 per hour

Approach volume = 323 vehicles per hour

Mean speed of non-delayed through vehicles = 46 miles per hour

Using the chart for a speed of 50 miles per hour and the above values of the two variables it can be seen that the resulting point lies in an area that states that the benefits will repay the costs of the deceleration lane within a 5 year period. This is in agreement with the conclusion reached previously.

## Example 2

Average number of right turns for the five year

period 1969 to 1974 = 52 per hour

Average approach volume for the five year period

1969 to 1974 = 219 vehicles per hour

Mean speed of non-delayed through vehicles = 31 miles per hour.

Using the chart for a speed of 30 miles per hour and the above values of the variables it can be seen that the resulting point lies in an area that states that the benefits will not repay the costs of a deceleration lane within a five year period.

Average number of right turns for the ten year period

1969 to 1979 = 57 per hour

Average approach volume for the ten year period

1969 to 1979 = 238 vehicles per hour

Mean speed of non-delayed through vehicles = 31 miles per hour.

Using the chart for a speed of 30 miles per hour and the above values of the variables it can be seen that the resulting point lies in an area that states that the benefits will repay the costs of a deceleration lane within a ten year period. This is also in agreement with the conclusion reached previously.

## RESULTS AND FINDINGS

The results and findings of this research project, which developed an economic warrant for the construction of right-turn deceleration lanes, are as follows:

1. Delays caused by right-turning vehicles to through vehicles are almost totally eliminated at locations with deceleration lanes.
2. Accidents involving a through vehicle and a right-turning vehicle did not occur at the three study locations with deceleration lanes; however, a few such accidents did occur at almost every study location without deceleration lanes.
3. An equation was developed that predicts the amount of delay at a location for the daylight-weekday hours, Monday through Friday, 6 A.M. to 6 P.M. This equation is:

$$SDH = -219.0 + 2.05\ X_5 + 0.37\ X_2 + 1.94\ X_6$$

where

SDH = the seconds of delay per hour to the approach through traffic caused by right-turning vehicles

$X_5$ = the number of right turns per hour in the approach traffic

$X_2$ = the approach traffic in vehicles per hour

$X_6$ = the mean speed of the non-delayed through vehicles in feet per second

This equation explained 76 percent of the variability in the data used to predict SDH. Variable $X_5$ is the most significant variable in the predicting equation; however, variables $X_2$ and $X_6$ also make important and approximately equal contributions to the equation.

4. In the development of the prediction equation, variables that were found to be unimportant were:
   a) The grade, with a range of 0 percent to 8 percent, had a correlation of -0.090 with delay.
   b) The width of approach, with a range of 10 feet to 14 feet, had a correlation of -0.045 with delay.
   c) The location, rural or urban, had a correlation of 0.206 with delay.
5. Accidents occurring at the study locations were too few in number and too variable by location to permit development of a reliable prediction equation.
6. This research proposes that an economic warrant be used for determining when a right-turn deceleration lane should be constructed. Such construction becomes feasible when the annual economic benefits resulting from decreased daytime delays are equal to or exceed the annual coats of constructing, operating and maintaining such a lane. Benefits from fewer accidents and less night time delay

should be considered in marginal situations where benefits from less delay during the daylight hours, 6 A.M. to 6 P.M., do not justify the construction of a right-turn deceleration lane.

## SUGGESTIONS FOR ADDITIONAL RESEARCH

During the conduct of this research, several suggestions for additional research have been noted. The more important of these are:

1. An equation to predict delay (SDH) was developed for the daylight-weekday hours, Monday through Friday, 6 A.M. to 6 P.M. Inclusion of delays during night time hours and for weekends would be valuable for more accurately estimating total benefits.
2. A reliable equation to predict the number of accidents at a location could not be developed because data available was too little and too variable. A reliable prediction method for accidents, however, is desirable.
3. Delays to through vehicles caused by right-turning vehicles were measured in the field. It is suggested that simulation could be used to determine average delays to through vehicles caused by right-turning vehicles. Such a technique could be used to extend the findings of this research to highways with other volumes.

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# BIBLIOGRAPHY

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# APPENDIX A

# GEOMETRICS OF THE STUDY LOCATIONS

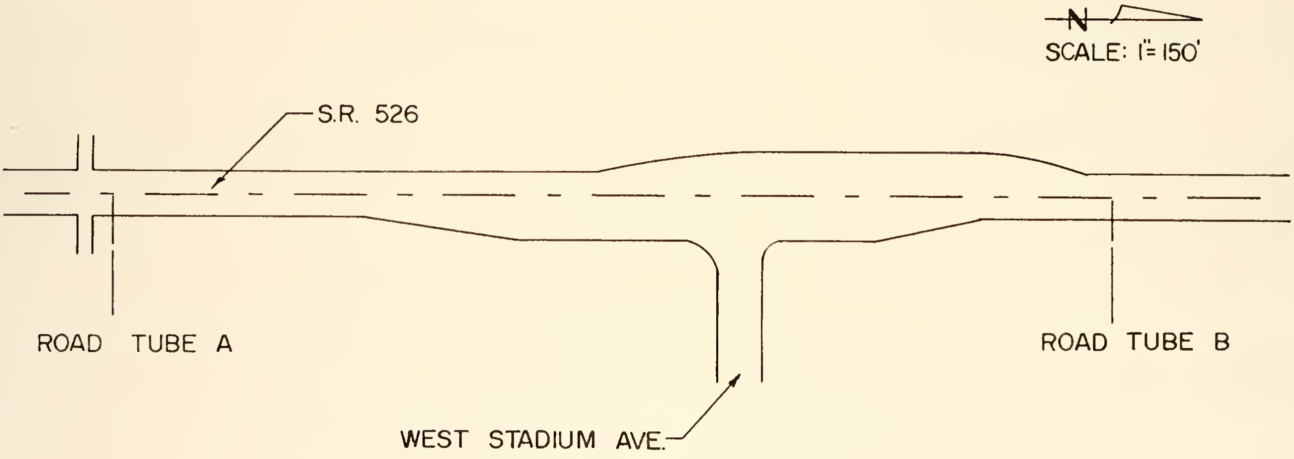

FIGURE 10 - S.R. 526 & WEST STADIUM AVENUE
SITE NUMBER 1

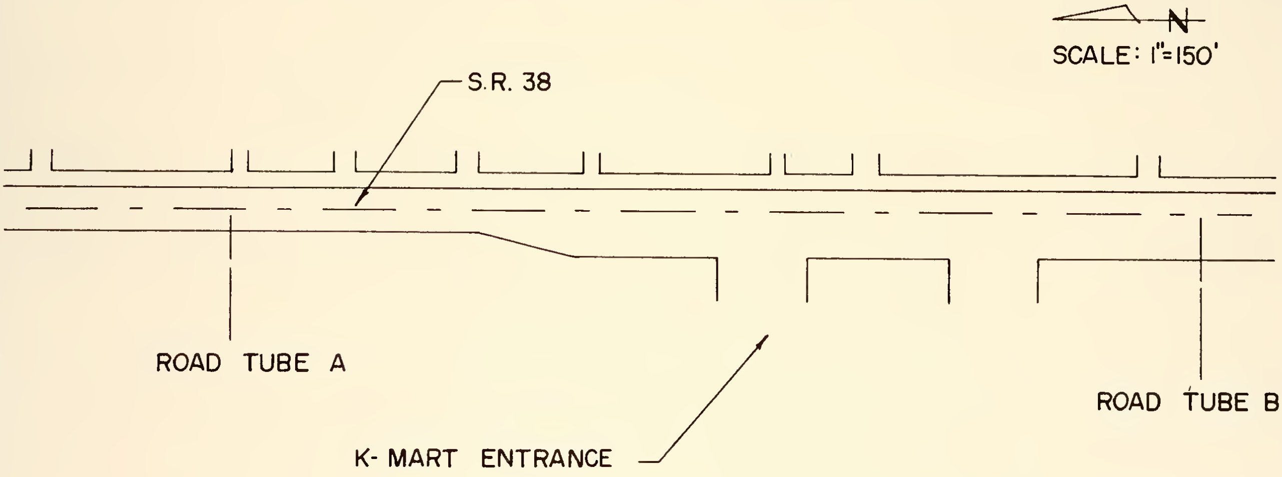

FIGURE 11 - S.R. 38 & K- MART SHOPPING CENTER
SITE NUMBER 2

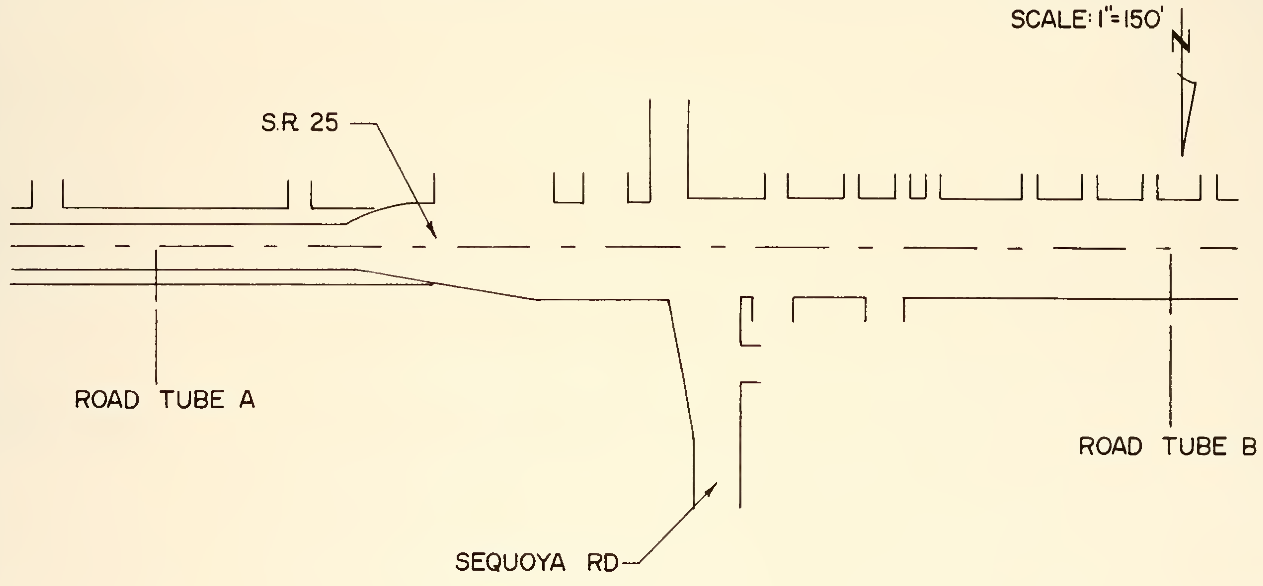

FIGURE 12 - S.R. 25 & SEQUOYA ROAD
SITE NUMBER 3

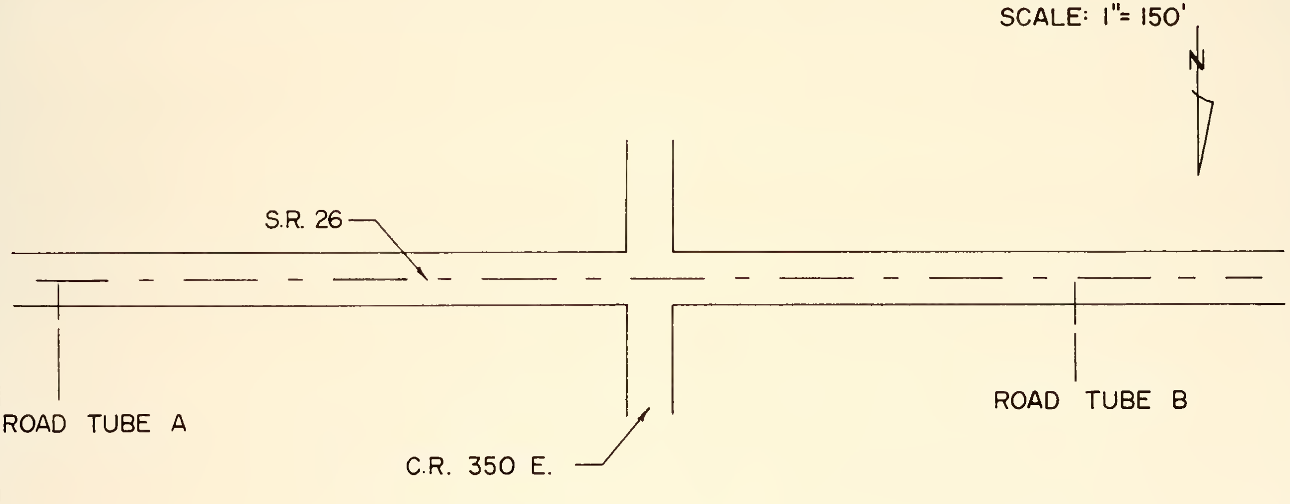

FIGURE 13 - S.R. 26 & COUNTY ROUTE 350 EAST
SITE NUMBER 4

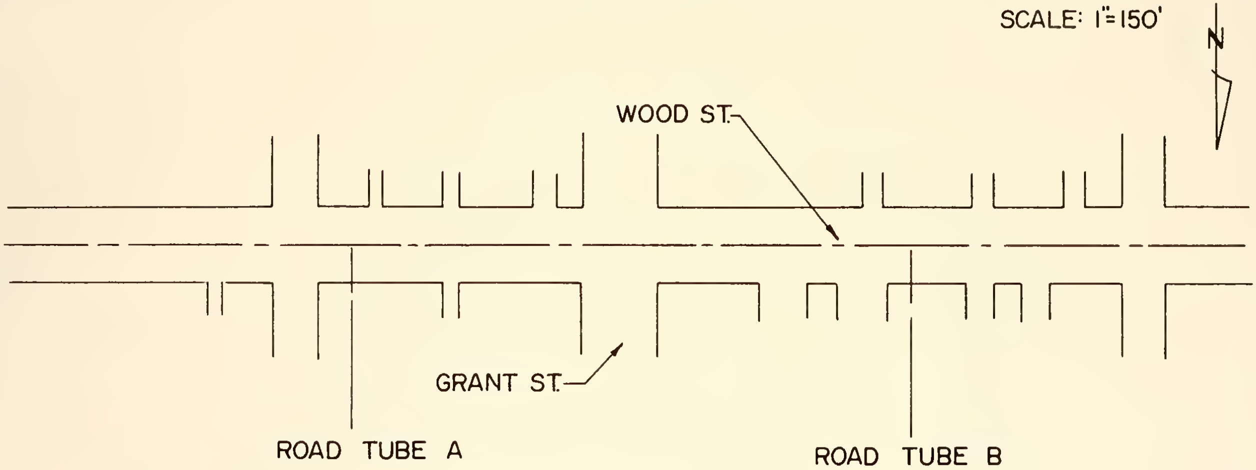

FIGURE 14- WOOD & GRANT STREETS
SITE NUMBER 5

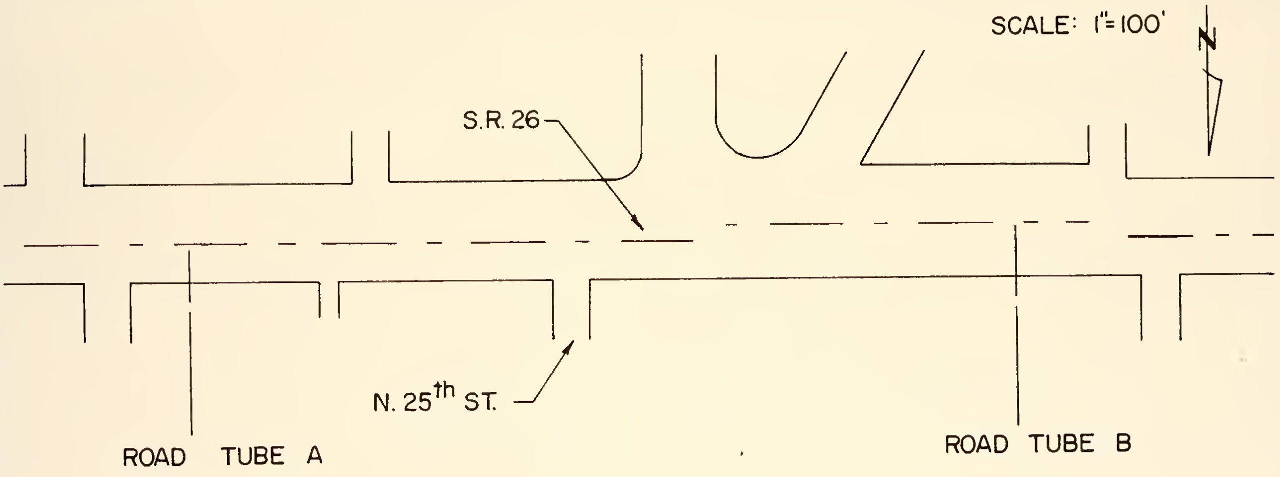

FIGURE 15- S.R. 26 & NORTH 25th STREET
SITE NUMBER 6

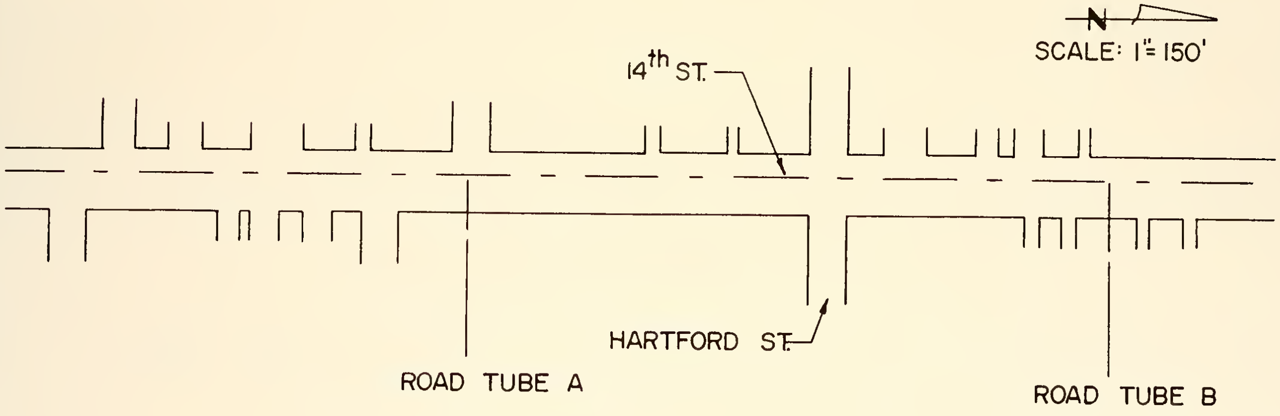

FIGURE 16 - 14th & HARTFORD STREETS
SITE NUMBER 7

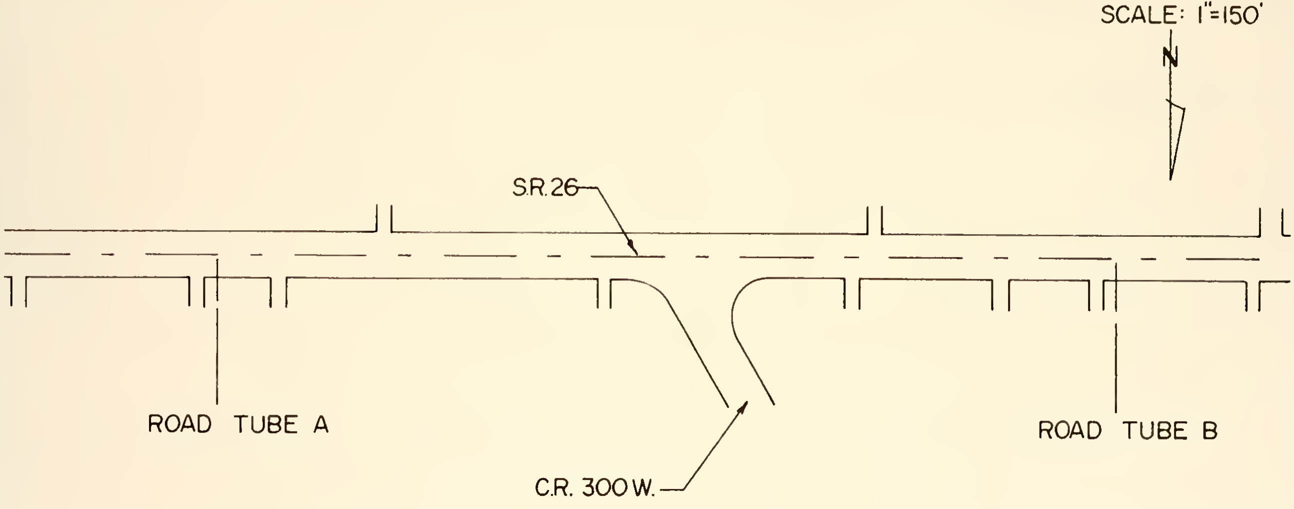

FIGURE 17 - S.R. 26 & COUNTY ROUTE 300 WEST
SITE NUMBER 8

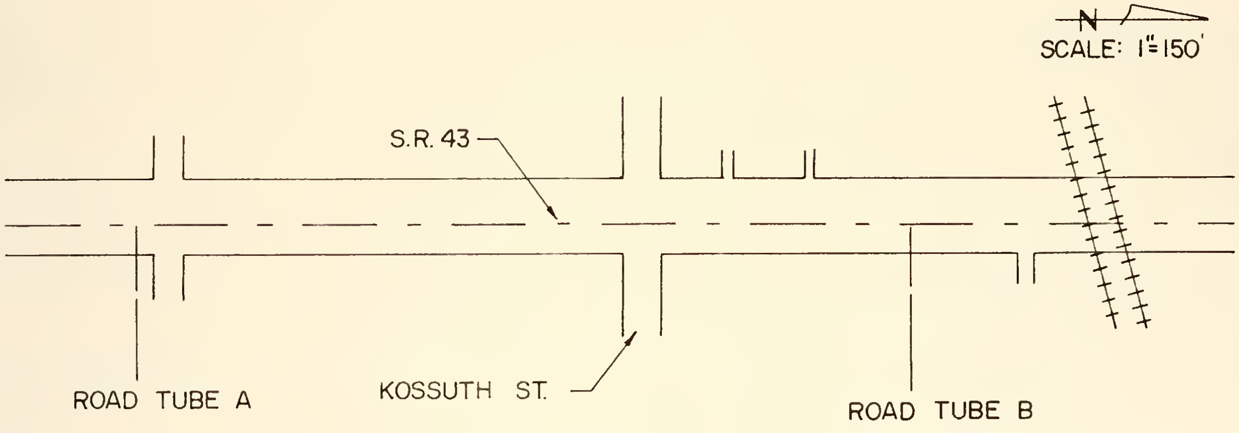

FIGURE 18 - S.R. 43 & KOSSUTH STREET
SITE NUMBER 9

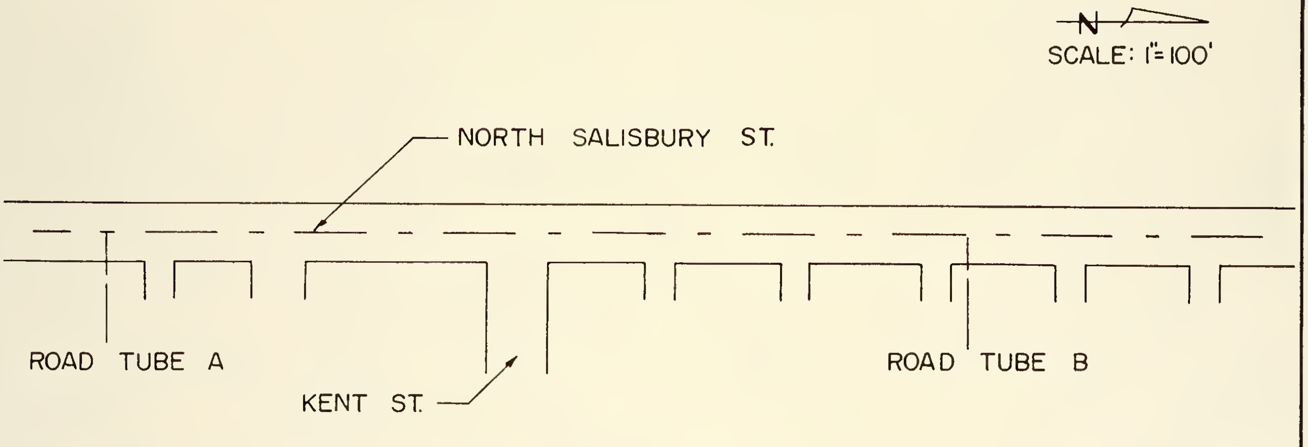

FIGURE 19 - NORTH SALISBURY & KENT STREETS
SITE NUMBER 10